TECHNICAL SUPPORT DOCUMENT REGARDING ADVERSE IMPACT DETERMINATION

FOR SHENANDOAH NATIONAL PARK

BY

AIR QUALITY DIVISION AND SHENANDOAH NATIONAL PARK

NATIONAL PARK SERVICE

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1.0INTRODUCTION

1.1 Purposes and Values of Shenandoah National Park

Shenandoah National Park (NP), established in 1926, consists of 195,382 acres that lie along the crest of the Blue Ridge Mountains in northern Virginia. As a unit of the National Park System, Shenandoah NP is managed consistent with the general mandates of the Organic Act of 1916 which states that the National Park Service shall:

> promote and regulate the use of . . . national parks . . . by such means and measures as conform to the fundamental purpose of the said parks, . . . which purpose is to conserve the scenery and the natural and historic objects and wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations. 16 U.S.C. 1.

The 1978 amendments to the Organic Act further clarify the importance Congress placed on protection of park resources as follows:

> The authorization of activities shall be construed and the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by the Congress. 16 U.S.C. 1a-1.

In addition to the mandates of the Organic Act, the protection of Shenandoah NP is guided by the Wilderness Act of 1964 with respect to over 80,000 acres of the park designated as wilderness, the largest concentration of such land in the eastern United States. The Wilderness Act defines wilderness as:

> an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain... an area of undeveloped Federal Land retaining its primeval character and influence... which is protected and managed so as to preserve its natural conditions. 16 U.S.C. 1131(c).

The Wilderness Act also states that wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use.

In addition to the general mandates of the NPS Organic Act and Wilderness Act, the legislative history specific to Shenandoah NP indicates that Congress intended the park to be a natural place, existing as an example of the Southern Appalachian portion of primitive America. The committee report to the bill securing the lands for Shenandoah National Park, was written by five "outstanding experts on parks" (House Rep. No. 1320, 68th Congress, 2nd Session). It contains discussion on air quality related values crucial to the park. The committee laid down six requirements in seeking an area in the Southern Appalachian Mountains for inclusion in the national park system. First among those was "Mountain scenery with inspiring perspectives and delightful details." Another of their requirements was "preserving outstanding features of the Southern Appalachians as they appeared in the early pioneer days."

The committee of experts reported that the areas within the Southern Appalachian ranges "fill the definition of a national park because of beauty and grandeur of scenery, presence of a wonderful variety of trees and plant life and possibilities of harboring and developing the animal life common in the precolonial days but now nearly extinct." Their report describes various "splendid" views and the "great scenic value" of the area. The committee concludes that the area's: "fine scenic and recreational qualities" as well as "its splendid primeval forest," "potential as an animal refuge of national importance," its "historic interest," and especially its scenic views and particularly the views along the then possible skyline drive along the continuous ridge, all recommend it for national park designation. In underscoring this latter point, Congress appropriated funds in 1931 to begin construction of Shenandoah NP's most famous visitor facility, the Skyline Drive, which was intended to provide spectacular views of the Shenandoah Valley and the Piedmont.

It is clear from the legislative history of Shenandoah NP that Congress intended for the park's natural, scenic, and historic resources to be used and enjoyed, without degradation, by great numbers of visitors each year.

In furtherance of the foregoing park purposes, resource management objectives for Shenandoah NP include the following: (1) vistas from the Skyline Drive, developed areas, and trails will provide clear views of natural and cultural environments; and (2) native, rare, endangered, and relict species, habitats, and communities will be protected and perpetuated.

1.2 Clean Air Act Requirements

In 1970, Congress passed the Clean Air Act (the Act), establishing a national policy toward protecting and enhancing air quality. In 1977, Congress enacted the Clean Air Act Amendments that designate all national parks, established as of August 7, 1977, that exceeded 6,000 acres in size, as mandatory class I areas the greatest degree of air quality protection. There are 48 national parks, including Shenandoah, designated as class I. The Clean Air Act Amendments also contain a section that specifically requires visibility protection for mandatory Federal class I areas. Section 169A sets, as a national goal, the prevention of any future, and remedying of any existing, manmade visibility impairment in mandatory class I areas. The Act requires that reasonable progress be made toward the national goal.

Under the Prevention of Significant Deterioration (PSD) program of the Act, major sources of air pollution that propose to build new or significantly modify existing facilities in relatively unpolluted areas of the country ("clean air regions"), are subject to certain requirements generally designed to minimize air quality deterioration. Where emissions from new or modified facilities might affect class I areas, like Shenandoah NP, set aside by Congress for their pristine air quality or other natural, scenic, recreational, or historic values potentially vulnerable to air pollution, the Act imposes special requirements to ensure that the pollution will not adversely affect such values. In addition, the Act gives the Federal Land Manager and the Federal official charged with direct responsibility for management of class I areas an affirmative responsibility to protect air quality related values, and to consider in consultation with the permitting authority whether a proposed major emitting facility will have an adverse impact on such values.

The Clean Air Act establishes several tests for judging a proposed facility's impact on the clean air regions in general, and on the class I areas in particular. One such test is the "class I increment" test. The class I increments represent the extremely small amount of additional pollution that Congress thought, as a general rule, should be allowed in class I areas.

Congress realized, however, that in certain instances sensitive air quality related resources could be adversely affected at air pollution levels below the class I increments. Therefore, the Act establishes the "adverse impact" test, which requires a determination of whether proposed emissions will have an "adverse impact" on the air quality related values, including visibility, of the class I area. If the Federal Land Manager demonstrates to the satisfaction of the permitting authority that proposed emissions will adversely affect the air quality related values of the class I area, even though they will not cause or contribute to concentrations which exceed the class I increments, then the permitting authority may not authorize the proposed project. Thus, the adverse impact test is critical for proposed facilities with the potential to affect a class I area.

1.3 Adverse Impact Considerations

The legislative history of the Clean Air Act provides direction to the Federal Land Manager on how to comply with the affirmative responsibility to protect air quality related values in class I areas:

The Federal land manager holds a powerful tool. He is required to protect Federal lands from deterioration of an established value, even when class I numbers are not exceeded. . . While the general scope of the Federal Government's activities in preventing significant deterioration has been carefully limited, the Federal land manager should assume an aggressive role in protecting the air quality values of land areas under this jurisdiction. . . . In cases of doubt the land manager should err on the side of protecting the air quality-related values for future generations. Sen. Report No. 95-127, 95th Cong., 1st Sess. (1977).

The Assistant Secretary for Fish and Wildlife and Parks, as Federal Land Manager for class I areas managed by the National Park Service and U.S. Fish and Wildlife Service, has stated that air pollution effects on resources in class I areas constitute an unacceptable adverse impact if such effects:

1. Diminish the national significance of the area; and/or

2. Impair the quality of the visitor experience; and/or

3. Impair the structure and functioning of ecosystems.

(See, e.g., 47 FR 30223, July 12, 1982).

Factors that are considered in the determination of whether an effect is unacceptable, and therefore adverse, include the projected frequency, magnitude, duration, location, and reversibility of the impact.

In addition, the Federal visibility protection regulations, 40 CFR 51.300, et seq., 52.27, define "adverse impact on visibility" as:

.... visibility impairment which interferes with the management, protection, preservation or enjoyment of the visitor's visual experience of the Federal class I area. This determination must be made on a case-by-case basis taking into account the geographic extent, intensity, duration, frequency and time of visibility impairment, and how these factors correlate with: (1) times of visitor use of the Federal class I area, and (2) the frequency and timing of natural conditions that reduce visibility.... Id. 51.301(a)

1.4 Summary of Proposed Determination

This technical review document supports the Federal Land Manager's preliminary determination that although the class I increments may not be exceeded at Shenandoah NP, the increase in emissions resulting from the proposed PSD facilities listed below will, together with the already permitted emissions, have an unacceptable, adverse impact on visibility and other air quality related values in Shenandoah NP. Visibility, aquatic and terrestrial resources at Shenandoah NP are currently being adversely affected by air pollution. The Federal Land Manager reasonably believes that the effects of the additional sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOC) emissions associated with the electric generating stations proposed for the area would contribute to and exacerbate the existing adverse effects and are, therefore, unacceptable. In particular, increases in SO_2 and NO_x emissions associated with the pending permit applications are highly likely to: (1) exacerbate existing adverse visibility conditions at Shenandoah NP and cause a perceptible further degradation in park visibility; (2) hasten the acidification of sensitive streams within the park with resulting effects on aquatic life; and (3) threaten sensitive park vegetation. The proposed increases in VOC and NO_x emissions will contribute to already high ozone levels, at times already higher than the national standard, and impacts on ozone sensitive vegetation.

2.0PSD NEW SOURCE APPLICATIONS

Fifteen permit applications for the construction and operation of electric generating facilities in the Commonwealth of Virginia have been submitted recently, and more are expected. The Virginia Department of Air Pollution Control has granted construction permits for four of these facilities, while the other projects are at various stages in the permit review process. These proposed and permitted facilities are primarily significant emitters of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOC). These projects, their estimated emissions, and their current status are listed in Table 2-1 below.

Because many of the listed projects are still under review, the actual emissions allowed in the final permit for any one facility may be lower than those in the permit application. However, since additional generating facilities will be seeking permits in the near future, the figures used here for total amounts of the various types of air pollutants are conservative and reasonable for the purposes of this analysis. Table 2-1 shows that emissions in the vicinity of Shenandoah NP would increase significantly if the pending permit applications are approved by the Commonwealth of Virginia and these facilities are constructed and operated. Moreover, the Environmental Protection Agency (EPA) projects future growth in sulfur dioxide and nitrogen oxides in the Commonwealth of Virginia regardless of whether acid deposition legislation is enacted by Congress. (ICF, 1990).

3.0POTENTIAL IMPACTS OF PROPOSED EMISSION INCREASES ON VISIBILITY

In establishing the national visibility goal to remedy existing and prevent future visibility impairment in Section 169A of the Clean Air Act, Congress called for explicit recognition of the value of visibility in class I areas. Through a 1979 Federal Register process, the Department of the Interior determined and the Environmental Protection Agency (EPA) concurred that visibility is an important value in Shenandoah NP. See 44

FR 69122 (November 30, 1979). As a consequence of this determination, Section 169A of the Act, and the federal and State regulations it spawned, require reasonable progress be made towards the elimination of visibility impairment problems at Shenandoah NP.

TABLE 2-1: RECENTLY PROPOSED/PERMITTED ELECTRIC GENERATING STATIONS IN VIRGINIA

SOURCE NAME	DISTANCE/ DIRECTION FROM SHENAN-DOAH NP (km)	SO_2 EMISSIONS (TPY)*	NO_x EMISSIONS (TPY)*	VOC EMISSIONS (TPY)*	PROJECT STATUS
Hadson Power (Altavista)	103 S	599	961	97	PERMITTED
Hadson Power (Hopewell)	155 SE	519	956	97	UNDER REVIEW
Hadson Power (Southampton)	200 SE	799	1,602	97	PERMITTED
Hadson Power (Buena Vista)	62 SW	358	957	97	UNDER REVIEW
Virginia Turbo Power (Orange County)	35 E	841	1,130	27	UNDER REVIEW
Doswell Limited	110 SE	2,600	2,389	231	PERMITTED
Old Dominion Electric	115 SE	4,479	10,764	360	UNDER REVIEW
Mecklenburg Cogen.	125 SE	1,990	4,560	50	PERMITTED
Multitrade Limited	110 SW	937	850	344	UNDER REVIEW
Cogentrix Inc. (Dinwiddie)	150 SE	2,102	3,942	39	UNDER REVIEW
VA Power (Gravel Neck)	190 SE	1,200	1,204	20	UNDER REVIEW
Cogentrix Inc. (Richmond)	110 SE	1,708	3,942	39	UNDER REVIEW
Bear Island	130 SE	575	155	0	UNDER REVIEW
Bermuda Hundred Energy	150 SE	387	612	110	UNDER REVIEW
Commonwealth Cogen.	120 SW	995	2,280	25	UNDER REVIEW

TOTAL	20,089	36,304	1,633

* tons per year

3.1 Visibility at Shenandoah NP is Currently Significantly Impaired by Manmade Pollution

Under natural conditions, without the influence of air pollution, the annual average visual range in the eastern United States is estimated to be 150 km (+/- 45 km). (Trijonis, et al., 1990). Visibility is strongly affected by light scattering and absorption by fine particulate matter (<2.5 microns in diameter). Under natural conditions, the annual average fine particulate matter concentrations in the eastern United States would be about 3.3 ug/m^3 (Trijonis, et al., 1990). As explained further below, among the constituents of the fine particulate matter, fine sulfate particles (which result from the atmospheric conversion of gaseous sulfur dioxide emissions) are currently responsible for most of the visibility impairment throughout the East. Natural levels of sulfate have been estimated to be about 0.2 ug/m^3 on an annual basis. (Trijonis, et al., 1990).

Studies examining historic visibility trends in the East show that annual average visibility in the southeastern United States declined 60 percent between 1948 and 1983, with an 80 percent decrease in summer months and a 40 percent decrease in winter months. Visual range in rural areas of the East currently averages 20-35 km, substantially lower than the estimated 150 km natural condition. Many of the constituents of the haze that degrades visibility are not emitted directly but are formed by chemical reactions in the atmosphere. Gaseous "precursor" emissions from a source are converted through very complex reactions into "secondary" aerosols. Sulfur oxides convert into sulfuric acid and ammonium sulfate, nitrogen oxides convert to nitric acid and ammonium nitrate, and hydrocarbons become organic aerosols (Malm et al., 1989). Haziness over the eastern U.S. since the late 1940's has been dominated by sulfur. Declining visibility is well correlated with increasing emissions of sulfur dioxide. (Husar, 1989).

The National Park Service of the Department of the Interior has been monitoring visibility at Shenandoah NP since 1980 as part of its visibility monitoring network and more recently (1988) as part of EPA's national visibility monitoring network for class I areas known as the IMPROVE network. Initially, teleradiometers and cameras were used to monitor views and determine visual range during the non-winter seasons, although a few samples were collected during the winters of 1987 and 1988. In 1983, the NPS began monitoring fine particulate matter at Shenandoah NP using a Stacked Filter Unit (SFU) which was replaced by the more sophisticated IMPROVE sampler in 1988. In addition to providing a more accurate cut-point for fine particles less than 2.5 microns in diameter, the IMPROVE sampler allows for the collection and analysis of a greater number of atmospheric pollutants, such as chloride, sulfate, and nitrate ions, and elemental and organic carbon. In 1989, the teleradiometer was replaced by a transmissometer which directly and continuously measures light extinction.

The analysis of fine particle data collected at Shenandoah NP in 1988 and 1989 using the IMPROVE sampler, as presented in Table 3-1 and Figure 3-1, indicate that monthly average fine particle concentrations have ranged from 19.5-28.9 ug/m^3 during the summer (i.e., Jun-Sep), or six to nine times higher than the estimated annual average natural background concentration. The summer average of fine particle mass concentrations measured at Shenandoah NP during the period June 1982 to May 1986 using the SFU was 16 ug/m^3, whereas the average for the entire sampling period was 10 ug/m^3. Thus, summer and annual average fine particle mass concentrations are 5 and 3 times, respectively, the estimated natural background.

Recent analyses of data collected at Shenandoah NP have shown that sulfates are responsible for 70-85 percent of the visibility impairment (Malm, et al., 1987; Trijonis, et al., 1990). Based on the SFU data, the summer average sulfate concentration between 1982 and 1984 ranged from 8.5-10.2 ug/m^3, a forty to fifty-fold increase from natural background. Similarly, the 3-year average sulfate concentration of 5.8 ug/m^3 during the 1982-1986 time period has experienced an almost thirty-fold increase from natural background. Table 3-2 and Figure 3-2 provide tabular and graphical summaries of the SFU data from Shenandoah. The most recent data available from the IMPROVE sampler (see Table 3-1), show a summer 1989 average sulfate of 11.2 ug/m^3 and a 12-month average (Dec '88-Nov '89) of 6.4 ug/m^3, slightly higher than, but consistent with, the SFU data. On the average, organics are responsible for most of the remaining visibility impairment. (Malm, et al., 1987). Nitrate aerosols (resulting from atmospheric conversion of nitrogen oxide emissions) are generally responsible for only one percent of the visibility impairment and average less than 2 ug/m^3. However, at times, nitrates comprise 10-20 percent of the fine mass and could significantly affect visibility during some episodes. Thus, one can reasonably conclude that the existing poor visibility conditions at Shenandoah NP are likely a result of the dramatic increases in sulfate concentrations, primarily the result of increase in man-made sulfur oxide emissions in the region.

Using the data collected at Shenandoah NP using both teleradiometer (1980-1987) and transmissometer (1989-Present), one can describe the effect of the increased fine particulate and sulfate concentration on visibility at Shenandoah NP. Median visual range at Shenandoah NP ranges from 10-113 km, with an annual geometric mean (1987) of 65 km. In other words, the "average" visibility day at Shenandoah NP has experienced a degradation through time to one-tenth to three-fourth of estimated natural conditions, averaging approximately 40% of natural conditions on an annual basis. This degradation is likely attributable to increases in man-made sulfur oxide emissions. As can be seen from Figure 3-3, visibility conditions at the park show a strong seasonal pattern, with the worst visibility occurring during the summer. During summer months the average visibility ranges from 10-36 km, or less than one-quarter the estimated natural visual range. Tables 3-3 and 3-4 present the 10th, 50th, and 90th percentiles of teleradiometer and transmissometer data, respectively, collected at Shenandoah NP. Figures 3-3 and 3-4 are plots of these data on a seasonal basis. As can be seen from these figures and as stated earlier, visibility is poorest during the summer when visitation at Shenandoah NP is highest.

TABLE 3-1: SHENANDOAH NATIONAL PARK
IMPROVE PARTICULATE DATA ug/m^3

YEAR	MONTH	AMMONIUM SULFATE	NITRATE ION	SOIL	FINE MASS (<2.5 um)	TOTAL MASS PM10
1988	Mar	4.9	1.6	0.4	8.6	12.3
1988	Apr	5.2	1.7	0.6	11.5	14.5
1988	May	8.8	0.5	0.8	15.1	18.8
1988	Jun	8.5	0.8	0.6	23.0	23.7
1988	Jul	10.3	0.3	0.6	27.5	29.8
1988	Aug	10.8	0.3	0.6	28.9	40.9
1988	Sep	8.5	0.4	0.4	10.0	15.0
1988	Oct	4.2	0.7	0.4	7.7	11.9
1988	Nov	3.6	0.7	0.3	6.3	8.3
1988	Dec	2.2	0.5	0.2	4.4	6.4
1989	Jan	2.2	0.8	0.3	4.9	7.2
1989	Feb	3.5	1.5	0.3	6.6	9.2
1989	Mar	5.1	0.9	0.9	7.8	16.2
1989	Apr	5.7	0.6	0.4	9.7	12.8
1989	May	6.0	0.5	0.7	11.5	15.9
1989	Jun	11.1	0.4	0.8	20.4	23.1
1989	Jul	10.2	0.4	0.7	19.5	24.0
1989	Aug	12.3	0.4	0.5	20.3	22.2
1989	Sep	9.7	0.5	0.3	10.3	19.5
1989	Oct	5.0	0.7	0.4	9.3	14.3
1989	Nov	3.6	0.6	0.3	6.5	9.5

TABLE 3-2: FINE AMMONIUM SULFATE 10-50-90 PERCENTILE SEASONAL AVERAGES 1983-1987 SHENANDOAH NATIONAL PARK

		10th ug/m^3	50th ug/m^3	90th ug/m^3
Winter	'83	1.4	2.6	5.0
	'84	1.4	2.8	5.4
	'85	0*	0*	0*
	'86	1.2	3.2	8.3
	'87	0*	0*	0*
Spring	'83	1.9	3.5	6.2
	'84	3.3	5.0	7.8
	'85	2.9	5.4	10.7
	'86	3.1	5.4	10.3
	'87	1.01	2.6	6.6
Summer	'82	3.3	7.4	16.9
	'83	3.9	7.8	16.0
	'84	3.3	6.6	13.2
	'85	4.1	8.3	16.5
	'86	3.0	5.6	10.4
	'87	0.6	3.1	16.3
Fall	'82	2.1	4.5	9.5
	'83	2.1	4.5	9.5
	'84	1.6	3.7	8.3
	'85	1.3	4.0	2.4
	'86	1.0	2.9	8.0
	'87	0.4	1.9	8.9

* Denotes no data collected

TABLE 3-3: STANDARD VISUAL RANGE 10-50-90 PERCENTILES SEASONAL AVERAGES 1980-1987
TELERADIOMETER DATA
SHENANDOAH NATIONAL PARK

		10th (km)	50th (km)	90th (km)
Winter	'87	38	113	246
	'88	38	76	179
Spring	'80	18	41	94
	'81	15	28	52
	'82	0*	0*	0*
	'83	27	60	133
	'84	21	37	68
	'85	20	43	93
	'86	21	26	37
	'87	51	89	193
Summer	'80	10	26	66
	'81	10	26	65
	'82	3	17	78
	'83	6	19	56
	'84	11	25	59
	'85	13	36	98
	'86	21	26	105
	'87	23	30	82
Fall	'80	23	52	118
	'81	35	67	127
	'82	18	38	81
	'83	28	51	95
	'84	18	42	94
	'85	14	43	127
	'86	21	52	176
	'87	29	68	176

TABLE 3-4: STANDARD VISUAL RANGE 10-50-90 PERCENTILES SEASONAL AVERAGES
1989-1990 TRANSMISSOMETER DATA
SHENANDOAH NATIONAL PARK

		10th (km)	50th (km)	90th (km)
Winter	'89	9	45	91
Spring	'89	10	18	30
Summer	'89	6	10	19
Fall	'89	1	14	20
Winter	'90	5	12	17

The chronic visibility impairment at Shenandoah NP typically manifests itself as a uniform haze. Such impairment is a homogeneous haze that reduces visibility in every direction from an observer. It appears as though the observer were peering through a grey or white translucent curtain placed in front of the scene. Colors appear washed out and less vivid, and geologic features become less discernible or may disappear.

In a November 14, 1985, letter, the Department of the Interior informed the EPA that, with respect to this uniform haze, the NPS visibility monitoring program has shown that more than 90 percent of the time scenic views at Shenandoah NP (and other class I areas) are affected by anthropogenic pollution.

3.2 Estimated Impact of New Air Pollution Sources

As noted in the Introduction, the Federal visibility protection regulations, 40 CFR 51.300(a), 52.27(b), define "adverse impact on visibility" as visibility impairment which interferes with the management, protection, preservation or enjoyment of the visitor's visual experience of the Federal class I area. This determination must be made on a case-by-case basis taking into account the geographic extent, intensity, duration, frequency and time of visibility impairment, and how these factors correlate with: (1) times of visitor use of the Federal class I area, and (2) the frequency and timing of natural conditions that reduce visibility. Based on this general definition and the data summarized above, manmade pollution clearly cause adverse impacts on visibility at Shenandoah NP. Although the extent of the problem varies in magnitude, visibility at Shenandoah NP is substantially impaired most of the time.

Poor visibility is the single most frequent complaint made by visitors to Shenandoah NP. In a recent study conducted by the National Park Service and the EPA, over 1,800 citizens across the country responded to a questionnaire in which they were asked to rate the importance of visibility in national parks. Between 70 and 80 percent of the respondents stated that they were concerned about decreasing visibility; and 70 percent said that they were willing to pay a significant amount to prevent further degradation. Chestnut, et al., (1990).

Given the specific distances of the proposed air pollution sources from Shenandoah NP, it is unlikely that the proposed emissions would be visible as distinct, coherent plumes in the park. These sources are likely, however, to contribute to uniform haze, the more pervasive visibility problem in Shenandoah NP. In fact, NPS research has shown that both local (e.g., within 200 km) and long-distant sources contribute to such visibility impairment at Shenandoah (Gebhart and Malm, 1989). In addition to Virginia, source areas in the states of Ohio, Kentucky, West Virginia, Indiana, Michigan, and Illinois were estimated to contribute to the park's haze.

Given the existing impacts on the visibility at Shenandoah NP, **any** significant increase in emissions which contributes to visibility impairment at Shenandoah NP would adversely affect this class I resource. In addition, the cumulative impact of the emissions from the fifteen sources listed in Table 2-1 will cause a further perceptible degradation in visibility from existing conditions. More specifically, based on research on human perception of visual air quality, the NPS believes that a five percent change in extinction (or standard visual range) constitutes a lower-bound threshold which should be noticeable by a sensitive observer. A fifteen percent change in extinction represents an upper-bound threshold, i.e., the change would be noticeable to a casual observer. (Pitchford, et al., 1990). (EPA, 1979; Trijonis, et al., 1990)

As indicated above, sulfur dioxide and nitrogen oxide emissions in the vicinity of Shenandoah NP will increase significantly if the proposed new sources listed in Table 2-1 are constructed and operated. On a Statewide basis, the SO_2 and NO_x emission levels would increase by 7 and 22%, respectively, and the percentage increase in emissions in the vicinity of Shenandoah NP would be even greater. Based on emissions totals provided by the Virginia Department of Air Pollution Control, the proposed increases would represent a 37% and 113% increase in SO_2 and NO_x emissions, respectively, for all point sources located within 100 km of the park boundary. The Federal Land Manager believes it is reasonable to assume that the relationship between sulfur dioxide emissions and sulfate levels is linear (i.e. 1:1). In fact, models used by EPA past visibility studies have assumed such linearity (see, e.g., EPA (1985). Even if the relationship were not entirely linear, the percentage increase in areawide sulfur dioxide and nitrogen oxide emissions can reasonably be assumed to perceptibly further degrade visibility at Shenandoah NP and would severely hinder any future efforts in making reasonable further progress towards the elimination of this existing impairment.

In sum with respect to visibility, the Federal Land Manager believes that the cumulative increase in emissions from the proposed sources will contribute to existing adverse impacts on visibility at Shenandoah NP, and is likely to cause additional perceptible visibility degradation from current conditions at the park. The Federal Land Manager further believes that the significant sulfur and nitrogen oxide emission increases proposed for each listed source individually would contribute to existing adverse visibility impacts at the park. For both these reasons, allowing such significant increase in visibility-impairing pollutants would frustrate--rather than promote--achievement of the national visibility goal and the need to make reasonable progress toward that goal.

The EPA estimates that by the year 2010, sulfur dioxide emissions in the Commonwealth of Virginia will more than double. If pending amendments to the Clean Air Act are enacted, EPA estimates that sulfur dioxide emissions in the eastern United States will be reduced by almost 50 percent; however, EPA also estiamtes that, despite the overall reduction in the East, the emissions within the Commonwealth of Virginia will increase, particularly between now and 2005. (ICF, 1990). Thus, additional efforts are needed to limit projected and proposed increases in atmospheric loadings of emissions likely to contribute to visibility degradation at Shenandoah NP, where visibility is such an important value.

3.3 Potential Impact of Increased Emissions

Based on the above findings and discussion, the Federal Land Manager concludes that the present visibility conditions at Shenandoah NP meet the adverse impact criteria discussed above, and therefore, are adverse. Specifically, the present conditions interfere with the management, protection, preservation and enjoyment of the visitor's visual experience, thereby diminishing the national significance of the area. The Federal Land Manager also concludes that the effects of the additional SO_2, NO_x, and VOC emissions associated with the electric generating stations proposed for the area would contribute to and exacerbate the existing adverse visibility effects and are, therefore, unacceptable.

4.0 POTENTIAL IMPACT OF NEW SOURCES ON AQUATIC RESOURCES

The same sulfates and nitrates that are responsible for visibility impairment also contribute to acidic deposition. Over a decade of scientific research shows that serious impacts are occurring on aquatic ecosystems in Shenandoah NP.

4.1 Sensitive Watersheds in Shenandoah NP are on the Verge of Acidification

Shenandoah NP receives one of the highest acidic deposition loads of all the national parks. Precipitation chemistry is monitored as a part of the National Atmospheric Deposition Program (NADP) and the National Dry Deposition Network (NDDN). Records show an annual volume-weighted pH value of 4.22 and a sulfate concentration of 54.2 microequivalents per liter (ueq/L). Anthropogenic sources probably account for about 90 percent of the sulfate in this precipitation and at least 80 percent of the hydrogen ion. Consequently, a large potential exists for acidification of sensitive basins in the park.

Assuming that precipitation at remote locations in the world is similar to that of Shenandoah NP in preindustrial times, the total deposition of ions in precipitation has increased about six fold since industrialization. The cause of this increase is atmospheric emission of sulfur and nitrogen gases associated with fossil fuel combustion. These gases react in the atmosphere to form sulfuric and nitric acid, which occur as sulfate, nitrate and hydrogen ion when dissolved in precipitation. Hydrogen ion concentration has increased from a preindustrial pH of 5.0 or higher to an average pH of about 4.2.

In order to determine the sensitivity of streams in Shenandoah NP to acidification, six synoptic surveys of 56 streams that drain the park were conducted in cooperation with the University of Virginia and the U.S. Geological Survey (Lynch and Dice, 1985). Stream samples were collected from August 1981 through June 1982, and each sample was analyzed for alkalinity, major anions and cations, silica, and pH.

The results of these surveys showed that the flow-weighted alkalinity concentration of most streams is below 200 ueq/L, which is commonly considered the threshold of sensitivity. Stream-water sensitivity is strongly affected by drainage basin bedrock type. Streams draining the resistant siliceous bedrocks show extreme sensitivity (alkalinity below 20 ueq/L); streams draining granite and granodiorite show a high degree of sensitivity (20 to 100 ueg/L); and streams draining the metamorphosed volcanics show moderate to marginal sensitivity (101 to 200 ueq/L).

The strong relationship between bedrock type and stream-water chemistry in the park was evaluated statistically by multiple-regression analysis. This technique indicated that concentrations of alkalinity, silica, and base cations are strongly related to bedrock type, and that sulfate concentration is strongly related to geographic location. The regression equation for alkalinity is shown to be a useful tool for predicting sensitivity of unsampled streams within Shenandoah NP and for streams in areas with similar geology outside the park. Predicted values are generally within 30 microequivalents per liter of the measured value.

Following the determination that many park watersheds are highly sensitive to acidification, an intensive research effort was undertaken to quantify current impacts and to predict what future effects may be. The Shenandoah Watershed Study (SWAS) was initiated in 1979 as a cooperative research and monitoring program of Shenandoah National Park and the Department of Environmental Sciences at the University of Virginia (Galloway, Hornberger, Cosby, Webb, et al., 1981-90). It was expanded in scope twice since then as more information was gained. This major research effort is still ongoing. To date, it represents one of the longest monitoring records of watershed acidification in North America. The objective of the SWAS program is to understand the processes that govern biogeochemical cycles in Shenandoah NP's mountain watersheds. It is these cycles that are altered by acidic deposition.

4.2 Principle SWAS Findings

(1) Streamwaters in large areas of Shenandoah National Park are poorly buffered against acidification.

The sensitivity of Shenandoah NP streamwaters to acidic deposition is primarily a function of watershed bedrock. Differences in the composition and weathering properties of the park's major bedrock types have produced a range of soils with differing development and acid buffering capacities. These differences are, in turn, reflected in the acid buffering capacity, or alkalinity, of associated streamwaters.

Surface waters with alkalinity concentrations of less than 200 ueq/L are commonly classified as acid sensitive. Relative to this value, the Shenandoah NP streams associated with basaltic bedrock are classified as marginally sensitive. The streams associated with granitic bedrock are classified as sensitive, while the streams associated with silico-clastic bedrock (quartzite, sandstone, phyllitic shale) can be classified as extremely sensitive.

The ecological significance of these differing sensitivity or alkalinity ranges is best revealed by reference to biologically critical pH or acidity levels. Conditions are prohibitive or marginal for many fish and other aquatic species when pH values are less than about 6.0. Shenandoah NP streams associated with the basaltic bedrock typically have pH values in the favorable range of about 7.0 to 7.2. For streams associated with the granitic bedrock, the pH values are slightly lower (more acidic), with a range of about 6.5 to 6.8. The extremely sensitive streams associated with the silico-clastic bedrock have pH values in the critical range of about 5.1 to 6.2.(Webb, et al., 1989)

(2)Acidification of Shenandoah National Park streams is delayed by sulfate retention in watershed soils.

Consistent with observations made on other streams in the southeastern United States, a large proportion of the sulfate deposited in Shenandoah NP is not appearing in streamwaters. Approximately 60-70% of the sulfate deposited in park watersheds is being adsorbed by watershed soils. This differs from conditions observed for acidified surface waters in the northeastern U.S. and Canada where soils adsorb less sulfate and most of the sulfate deposited in watersheds is transported away by surface water.

Sulfate adsorption in watershed soils helps explain why severe surface water acidification has not been observed in Shenandoah NP. Adsorption, however, is a capacity-limited mechanism which provides only a temporary delay in the acidification process. As the adsorption capacities of watershed soils are exhausted, the sulfate concentrations and acidity levels in park streams will rise.

(3)Acidification of Shenandoah National Park streams is an ongoing process.

All basins in the park have been acidified by atmospheric deposition. Current acidification averages 50 ueq\L, which is fairly evenly distributed in Shenandoah NP. This acidification is manifest as a neutralization of stream-water alkalinity and/or an increase in the weathering-out of base cations from soils and rocks. These two processes are indistinguishable, but both have serious consequences in the park, especially in the extremely sensitive areas underlain by the Antietam and Hampton Formations. Because of the low "pre-acidification" concentration of stream-water alkalinity and the small reserve of available base cations in the areas, even modest changes due to acidic deposition have large impacts on stream-water chemistry. In the Antietam Formation, the most sensitive formation in the park, acidic deposition has resulted in stream water with an average pH of 4.99 and mineral acidity of 7 ueq/L. Acidification of basins in the other geologic formations also may be significant, but higher "pre-acidification" concentrations of stream-water alkalinity and base cations make it less apparent.

In addition, basins sensitive to acidic deposition, i.e., those containing poorly developed soils and resistant bedrock, do not necessarily respond the same as less sensitive basins when subjected to the same increase in the rate of base cation weathering. The reserve of available base cations for carbonic acid weathering reactions is normally small in sensitive basins. Thus, long-term acidification may severely deplete this reserve, thereby decreasing the potential for alkalinity-producing reactions in a basin and decreasing the capacity of soils and rocks to retain hydrogen ions from acidic deposition. The result is a drop in stream-water pH and perhaps an increase in the concentration of dissolved aluminum. Because less sensitive basins contain more weatherable minerals and better developed soils, the potential for significantly reducing the reserve of base cations available for carbonic acid weathering is much smaller.

Chronic acidification has been documented for both Deep Run and White Oak Run, two Shenandoah NP streams which have been intensively monitored since 1979. These streams are located in an area dominated by quartzites, sandstones, and shales. They represent the most sensitive class of park streams. Over an eight year period (1980-1988), the sulfate concentrations in both streams had risen about 2 ueq/L per year and alkalinity had declined 0.5 to 0.75 ueq/L per year. For Deep Run, the stream with least buffering capacity, hydrogen ion had increased about 0.4 ueq/L per year. In pH units, Deep Run had declined from about 5.6 to 5.3 over the timespan. White Oak Run, which had more buffering capacity, showed less increase in hydrogen ion. White Oak Run pH had declined from about 6.1 to 6.0. For both of these streams, the observed acidification indicates a state of ecological deterioration. The acidity level of White Oak Run is entering the biologically critical range, while the acidity of Deep Run is already well within the critical range.

4.3 Prognosis for Shenandoah NP Streams

Results from monitoring at weekly sampling sites indicate that acidification is ongoing in at least some Shenandoah NP streams: streamwater concentrations of sulfate are increasing, alkalinity is decreasing, and hydrogen ion is increasing. Even assuming no change in the present-day level of acid deposition, large changes in both the chemical and biological composition of the park's streams are expected.

Sulfate, which has already become the major dissolved anion in most park streams, will further increase in streamwaters as sulfate retention in watershed soil declines. This sulfate increase will result in a reduction in streamwater alkalinity and pH.

For those Shenandoah NP streams associated with base-poor soils and bedrock types, substantial reductions in streamwater alkalinity and pH may have already occurred and further reductions are expected. As further alkalinity is lost in these streams, pH values will decline to critical levels for many of the fish and other aquatic species which are now present. The first stages of these biological changes have been documented in recent studies. In 1985, Feldman and Conner evaluated the impact of acidic deposition on stream macroinvertebrates. This study indicated that the high alkalinity streams have a significantly greater number of species than the low alkalinity streams. Also, a significant difference in abundance and richness of invertebrates indicates that differences in community structure are associated with mean alkalinity of 27 and 235 ueq/L. These differences, along with the absence of some species at 27 ueq/L, are in agreement with findings from previous studies. The absence and significantly reduced abundance of many species suggest that a large proportion of the Ephemeroptera (mayfly) community is subject to physiological stresses related to alkalinity less than 50 ueq/L. Continued acidic deposition within Shenandoah NP will further reduce alkalinity and possibly further reduce the abundance and richness of Ephemeroptera in both groups of streams.

Macroinvertebrates are important prey for vertebrates such as native brook trout, and the reductions in Ephemeroptera abundance and richness due to low alkalinity (low buffering capacity) may jeopardize these fish populations in Shenandoah NP in the future. The results of these changes will be catastrophic to ecological balances in these streams.

4.4 Potential Impact of Increased Emissions

In conclusion, based on the above studies, the Federal Land Manager concludes that the present aquatic effects at Shenandoah NP meet the adverse impact criteria discussed above, and therefore, are adverse. The Federal Land Manager also concludes that the effects of the additional SO_2 and NO_x, emissions associated with the electric generating stations proposed for the area are unacceptable because they would contribute to the existing adverse aquatic effects by exacerbating and hastening ongoing acidification.

5.0 POTENTIAL IMPACTS ON TERRESTRIAL EFFECTS

The Federal Land Manager is also concerned about existing effects on sensitive terrestrial park resources. A summary of the available air pollution effects literature for each pollutant (SO_2, NO_x, and ozone) is provided below, followed by a discussion of the existing ozone and sulfur dioxide levels at the park, and the existing and potential effects on park resources at these levels.

5.1 Sulfur Dioxide (SO_2) Effects

Sulfur dioxide, a byproduct of the combustion of fossil fuels, such as coal and oil, was probably one of the earliest recognized air pollutants. This gas enters vascular plants through the stomata. Under humid conditions, SO_2 can even stimulate stomatal opening, thereby allowing greater entry of other gaseous pollutants that are often associated with it. Also, conditions that usually enhance stomatal opening, i.e., high humidity and high light intensity, are the same ones that increase sulfur dioxide absorption in laboratory experiments (Ziegler, 1975). Sulfate accumulates in plants exposed to SO_2, and the accumulation increases with their photosynthetic activity. At low doses, transpiration increases because the stomata have been stimulated to open. At higher doses; however, the stomata collapse and transpiration is reduced. In broadleaf plants, chlorophyll is decomposed and visible injury in the form of interveinal or marginal chlorosis/necrosis results (Mudd, 1975, Jacobsen and Hill, 1970). Conifer needles become dry, brown, and brittle. Biochemical effects of SO_2 include reduction in carbon dioxide (CO_2) uptake with a resulting decrease in photosynthesis, decreased metabolism, decrease in the protein content of leaves, enzyme inactivation (Mudd, 1975), decrease in DNA synthesis in higher plants, and a reduction in terpene production in conifers (Ziegler, 1975).

High relative humidity has been shown to enhance SO_2 uptake. In one study, foliar uptake increased two- to threefold with an increase in relative humidity from 35 to 75% (McLaughlin and Taylor, 1981). Conifers have a marked sensitivity to SO_2. Sitka spruce (Picea sitchensis) were fumigated with SO_2 then exposed to cold temperatures (Freer-Smith and Mansfield, 1987). This treatment led to a decrease in the number of buds that survived compared to controls. Garsed and Rutter (1984) tested Scots pine (Pinus sylvestris) and Sitka spruce under regimes of fluctuating SO_2 concentrations and found reduced root weight and leaf production and increased leaf fall. The effects were worse during the second year of treatment. They concluded that the main determinant of growth effects was average, not peak, SO_2 concentration. Spruce (Picea abies) in a fumigation study showed a significant decrease in CO_2 uptake and wood production without any accompanying visible injury (Keller, 1980). In another paper, Garsed and Rutter (1982) concluded that there was a lack of correlation between sensitivities to acute and chronic injury in the conifer genotypes they tested. They cautioned that the use of high concentrations of SO_2 in fumigation studies may give misleading results in experiments designed to investigate physiological mechanisms of resistance to chronic injury. Studies on the effects of sulfur dioxide on vascular plants report a tendency for

SO_2 to suppress root growth more than shoot growth, making the plants more vulnerable to drought stress (Lechowicz, 1986).

The structural characteristics of lichens and bryophytes make them particularly susceptible to the effects of air pollution. For this reason, they are often used as biomonitors. Because they are adapted to absorb moisture, they consequently absorb ambient pollutants (Rhoades, 1988). Lichens are almost entirely dependent on the atmosphere for their nutrients and moisture. In addition, unlike vascular plants which are able to close their stomata at night, lichens are exchanging gases with the atmosphere all the time. Sulfur dioxide interrupts the lichen's photosynthetic process by degrading the chlorophyll in the algal chloroplasts. This disrupts the association between the algal and fungal components of the lichen. Sulfur dioxide also causes an efflux of potassium that could alter membrane permeability. Lichens trap particulates and accumulate sulfur and heavy metals. Because of their low metabolic rate, they have a limited ability to respond to abrupt environmental changes (Anderson and Treshow, 1984).

Sensitive species of lichen grow poorly or are missing from areas with high sulfur concentrations. One study showed all epiphytic lichens absent from an area with mean annual ambient air levels of 170 ug/m^3 (0.06 parts per million (ppm)) SO_2. Sensitive species were severely depleted above 60 ug/m^3 (0.02 ppm), and effects were measurable as low as 30 ug/m^3 (0.01 ppm) of SO_2 (Treshow and Anderson, 1989). McCune (1988) showed that the variation in lichen community composition and cover were correlated with mean annual ambient air SO_2 levels. A mean annual concentration of 30 ug/m^3 (0.01 ppm) of SO_2 may injure sensitive individuals of the species Usnea, Lobaria, Ramalina, and Cladonia. Lichens growing on acid substrates are more sensitive to SO_2 than those growing on basic ones. Anderson and Treshow (1984) cited a study that showed a correlation between the concentration of atmospheric SO_2 and tree bark acidity. The number of epiphytic lichens declined as the pH of the tree bark decreased.

Although lichens are often overlooked members of the plant community, they nevertheless play a very important role in the ecosystem. At high elevations they stabilize fragile tundra soil. They are the pioneers of plant succession in disturbed environments. Lichens provide homes for invertebrates, and some contain blue-green bacteria which fix nitrogen, e.g., cryptogamic crusts in desert ecosystems (Rhoades, 1988). Lichens participate in mineral cycling by releasing organic compounds when they decompose. They are a good source of carbohydrates and are eaten by mites, insects, and gastropods, as well as deer and other vertebrates (Nieboer et al., 1978). Additionally, they are an important component of the biodiversity of natural ecosystems.

Sulfur dioxide has been shown to have a synergistic, or potentiating, effect when mixed with ozone (Mudd, 1975). Carlson (1979) reported on a study in which sugar maple (Acer saccharum), black oak (Quercus velutina), and white ash (Fraxinus americana) were fumigated with equal concentrations of SO_2 and ozone under conditions of high humidity and light intensity. In addition to visible foliar injury, photosynthesis was decreased significantly in both sugar maple and white ash. The photosynthetic decrease recorded when the two gases were mixed was much greater than that observed when each pollutant was used alone. Sulfur dioxide and nitrogen dioxide (NO_2) have also been shown to produce a synergistic response in plants in fumigation studies (Taylor et al., 1975).

Sulfur dioxide effects have also been observed on other components of the ecosystem. Microbial communities of the forest soil are important for the maintenance of nutrient cycling. Sulfur dioxide decreased bacterial colonization of the upper soil horizons and caused an alteration of natural selection to bring about changes in species diversity and abundance. Other changes observed included a decrease in soil respiration of the fermentation horizon, decreased decomposition of cellulose, organic matter and carbon compounds in the soil, decreased nitrogen fixation, and an increase in the amount of sulfur in the humus (Lettl, 1984). Microbes that were able to utilize the sulfur were favored. Sulfide, hydrogen sulfide (H_2S) and sulfite were all found to be toxic to soil microfauna, but SO_2 was determined to be the most toxic sulfur compound (Lettl, 1985).

Sulfur dioxide was also found to alter the incidence of plant parasitism (Heagle, 1973). Rust diseases and wood-destroying fungi were found to be very sensitive to SO_2, and the incidence of foliar disease decreased in high concentration areas. While this may, at first, appear to be a positive effect, it could have a negative impact on plant succession and nutrient cycling. The incidence of wood rot disease, caused by a fungus that normally invades weakened trees, was increased with ambient SO_2 concentrations. Hain and Arthur (1985) have suggested that atmospheric deposition is predisposing sensitive Fraser fir (Abies fraseri) to balsam woolly adelgid (Adelges piceae) infestation and mortality.

A number of studies performed on a grassland prairie in Montana documented the effects on fauna of SO_2 fumigation at concentrations below the National Ambient Air Quality Standards (NAAQS). Soil microarthropods representing three main trophic groups--herbivores, fungivores, and predators--decreased on fumigated plots compared to controls. The greatest effects were seen in the first half of the growing season when soil water content was high. Leetham et al., (1980) theorized that the population changes were due either to direct SO_2 toxicity or to a reduction in food sources due to the fumigation. A decrease in the number of saprophagous beetles was also observed (Bromenshenk 1980, 1979). This appeared to be a behavioral response as the beetles were observed to move to control (non-fumigated) areas. These beetles contribute to a quick turnover of nutrients and are a prey item for amphibians and insectivorous birds. There was a trend toward a decrease of the grasshopper (Acrididae) population with increasing SO_2 concentration and exposure time (McNary et al., 1980). Above-ground arthropods decreased in density and/or biomass in fumigated plots compared to controls (Leetham et al., 1980b). Finally, prairie deer mice (Peromyscus maniculatus) were observed to move out of fumigated areas relative to control plots (Chilgren, 1978). Although these studies were performed in a grassland, which differs significantly from a forest ecosystem, similar fauna inhabit forest niches. It is, therefore, reasonable to assume that similar responses to SO_2 might occur in a forest situation.

5.2 Nitrogen Oxides (NO_x) Effects

The greatest man-made source of NO_x is the high temperature combustion of fossil fuels. During combustion, some of the nitrogen in the air and fuel is oxidized to nitrogen oxide (NO) and nitrogen dioxide (NO_2). Through photochemical reactions involving the absorption of sunlight and interactions with hydrocarbons and oxygen, atmospheric NO is converted to NO_2, and some NO_2 is consumed in the production of ozone (O_3), with peroxyacyl nitrates (PAN's) given off as secondary pollutants (Taylor et al., 1975). Peroxyacyl nitrates have been shown to be highly phytotoxic (Mudd, 1975b). They cause glazing or bronzing of the lower surface of leaves, indicating damage of the mesophyll cells around the stomatal cavity. Sensitive species have been shown to be injured by levels as low as 20 parts per billion (ppb) for a 2 to 4 hour exposure period. Peroxyacyl nitrates have been reported to reduce the metabolism of cell wall sugars, thereby inhibiting coleoptile growth. Other biochemical effects include inhibition of starch mobilization in the dark, reduced photosynthesis, and inhibition of fatty acid synthesis (Mudd, 1975b). Herbaceous plants are particularly sensitive to PAN (Davis and Wilhour, 1976).

Nitrogen oxide and NO_2 are also phytotoxic. Laboratory experiments on snap beans (Phaseolus spp.) showed that atmospheric uptake of NO_2 takes place rapidly (Rogers et al., 1979). Nitrogen dioxide reacts with water in the leaves to form nitrous and nitric acids. When the acids exceed a certain threshold, the tissues of the leaf are injured. Characteristic visual symptoms include brown or black spots--especially on the margins of the leaves--associated with necrosis, and an overall waxy appearance. Injury is exacerbated under moist conditions, and studies show that nighttime fumigation causes more severe injury. Nitrogen oxide has been shown to reduce CO_2 absorption and photosynthesis, while NO_2 causes growth depression, increases leaf drop and reduces yield (Taylor et al., 1975).

Nitrogen addition through atmospheric NO_x deposition can have a profound effect on the ecosystem in two ways. First, it has been shown that the addition of nitrogen acts as a fertilizer to plants (Van Cleve and Oliver, 1982, Ekwebelam and Reid, 1984). Zeevaart (1976) documented the addition of atmospheric nitrogen to fumigated plants by measuring the increase in protein content of the leaves. Growth stimulation is a common response of broad-leaf and conifer trees and herbaceous plants to small amounts of NO_2 (Okano et al., 1989, 1988, 1986). New growth that occurs too early in the season could enhance sensitivity to an early spring frost (Freer-Smith and Mansfield, 1987). Alternatively, unnatural fertilization causes plants to grow later into the fall. Plants are also, therefore, more susceptible to frost damage in the winter. Friedland et al., (1984) theorized that a possible cause of red spruce (Picea rubens) decline in the eastern United States over the past few years might be due to anthropogenic nitrogen input. This could delay cuticle thickening on needles, leaving the trees more susceptible to damage from early frost or desiccation.

Second, the spatial distribution of nitrogen significantly influences community structure (Robertson et al., 1988). Wood and Bormann (1977), showed that eastern white pine (Pinus strobus) seedlings increased productivity under conditions that simulated acid rain. This indicates that white pine could be favored over less acid-tolerant species in the forest. In a study of secondary succession, it was shown that plant biomass and height significantly increased and species diversity significantly decreased with added nitrogen (Tilman, 1987). Initial species abundance did not make a difference in terms of interspecies competition. Nitrogen addition led to a period of transitional dominance by certain species. On experimental fields, more than 60% of the species had been displaced from high-nitrogen treatment plots within three years.

5.3 Ozone (O_3) Effects

Ozone is formed in the atmosphere in a complex reaction involving molecular oxygen, existing ozone, nitrogen dioxide, nitrogen oxide, and hydrocarbons. Ozone injury is much more severe in daylight hours when the leaf stomata are open. Visible symptoms of ozone damage include necrosis, chlorosis, and a flecking of the upper leaf surface (Jacobsen and Hill, 1970). The major sites of damage inside the leaf are the palisade parenchyma cells. The biochemical effects of ozone on vascular plants include inhibition of enzymes involved in cell wall synthesis, modification of amino acids, proteins, and unsaturated fatty acids, and increased water permeability leading to water loss from the leaves (Heath, 1975). Montes et al., (1983) reported that increased ozone levels reduced nitrogen fixation in a clover field. It has been shown that the most metabolically active cells are more prone to injury. When chlorotic areas were examined under light and electron microscopes, it was found that the changes in cell structure that occurred with ozone damage were similar to the changes associated with leaf senescence (Karenlampi, 1986). The author believed that this was not a primary effect of ozone injury, but rather a secondary effect due to the slow death of malfunctioning tissue.

Numerous studies have been done on the effect of anthropogenic ozone on plants under both laboratory and field conditions. Unfortunately, many of the laboratory fumigation studies were done at ozone concentration and exposure levels that do not mimic conditions found in nature. However, studies conducted under an exposure regime of average daily 7-hour concentrations of 0.04 to 0.07 ppm of ozone during the growing season recorded reduced crop yield and decreased tree growth without accompanying visible foliar injury (NAPAP, 1990). This fumigation regime is thought to be a realistic estimation of the situation that occurs in major agricultural areas of the United States. Reich and Amundson (1985) fumigated four tree and three crop species under a number of similar growing season regimes. They found that long-term exposure to ozone reduced photosynthesis and accelerated leaf aging. The authors concluded that fast-growing plants with high net photosynthetic rates, like crop species, have a higher ozone uptake rate than plants, like tree species, with lower conductance rates. However, they pointed out that while crops are exposed for only one growing season, trees may experience reductions in growth that are compounded over many years.

In other studies, eastern white pine, white oak (Quercus alba), and white ash were reported to be very sensitive to ozone (Hasbrouck, 1985). Ozone caused a decrease in CO_2 uptake and photosynthesis and a decrease in sugar production. Slash pine (Pinus elliottii) exposed to ozone fumigation that simulated the natural condition by including diurnal cycling were adversely affected by chronic exposure (Hogsett et al., 1985). Reduced root and top growth reflected a reduction in photosynthesis. An increased reduction in growth was seen with an increased level of exposure. Visible injury symptoms were minor; however, a significant reduction in root growth occurred even before visible injury was observed. Reduced root growth implies a decrease in the storage reserves necessary for breaking dormancy and surviving climatic stress. Grulke et al., (1989) reported that increased ozone concentrations adversely affected the carbon balance in giant sequoia seedlings (Sequoiadendron giganteum). In a study on ponderosa pine (Pinus ponderosa), it was shown that as visible foliar injury increased, specific leaf weight decreased (Ewell et al., 1989). Specific leaf weight is highly correlated with photosynthesis. Sensitive genotypes of ponderosa and Jeffrey (Pinus jeffreyi) pine exhibited visible foliar injury when the 24-hour average exceeded 0.05 to 0.06 ppm of ozone (Miller et al., 1969). Photosynthesis and stomatal response to light and temperature in ponderosa pine decreased with increasing dose. Chronically injured pines had reduced growth and vigor and produced fewer cones. Woodman (1987) also reported on a study in which trembling aspen (Populus tremuloides) exposed to ozone showed reduced growth without visible foliar injury. It should be apparent from these studies that there is a great deal of variability between, and even within, species in regards to the occurrence of foliar injury symptoms in conjunction with biochemical effects. Therefore, it cannot automatically be assumed that a plant is not being adversely impacted simply because there are no visible signs of injury.

Numerous studies have reported on the increased susceptibility of ozone-stressed plants to attack by pathogens and insects. The majority of the ozone-injured ponderosa pines in California were killed by western pine bark beetles (Dendroctonus brevicomis). Ozone fumigation of Jeffrey and ponderosa pines also led to an increased incidence of infection by root rot (Heterobasidion annosum Fr.) (Woodman, 1987). In a field study on these two species, James et al., (1980) inoculated freshly-cut stumps with a root pathogen, Fomes annosus. This fungus colonizes stumps and then infects surrounding trees through root contacts and grafts. Stump colonization increased with ozone injury. Mexican bean beetle (Epilachna varivestis) adults preferred to feed on soybean leaves (Glycine max) fumigated with ozone over non-fumigated leaves (Endress and Post, 1985). The beetles showed a marked preference for the leaves receiving the highest ozone concentration. Adults and larvae of willow leaf beetle (Plagiodera versicolora) preferred feeding on fumigated cottonwood leaves (Populus spp.), and gypsy moths (Porthetria dispar) preferred ozone-fumigated oak seedlings (Quercus spp.).

In studies of its effects on ecosystem stability, ozone has been shown to have a negative impact on plant reproduction (Lechowicz, 1986). Suppression of root growth makes plants more susceptible to drought stress. A study by Brown et al., (1987) suggested that ozone may increase frost sensitivity of Norway spruce (Picea abies), and may be contributing to the decline of high altitude forests. Cold sensitivity in plants is dependent on the integrity of cellular membranes which are thought to be a target of ozone injury. Ozone also appears to intensify the effects of natural stresses on red spruce in high elevation forests of the eastern United States (NAPAP, 1990). These forests are exposed to many more natural stresses than forests in lower elevations including such things as low fertility, extreme temperatures, lack of soil, high winds, and low water availability (Reich and Amundson, 1985).

5.4 Ambient Sulfur Dioxide Levels in Shenandoah NP

The National Park Service has also been monitoring ambient levels of SO_2 at the Dickey Ridge monitoring station since 1983. Since lichens accumulate sulfur continuously over time, the most meaningful data in relation to the potential impacts on sensitive vegetative resources are the annual average SO_2 readings. Table 5-1 presents the annual average SO_2 data recorded at the Dickey Ridge station from 1983-1989.

TABLE 5-1: DICKEY RIDGE AMBIENT SULFUR DIOXIDE (ANNUAL AVERAGE) READINGS (ug/m$^{3)}$

1983	1984	1985	1986	1987	1988	1989
13.1	16.4	17.7	17.6	18.3	21.4	19.0
59%DR	97%DR	94%DR	96%DR	40%/DR	55%DR	89%DR

DR = %Data Recovery

5.5 Sulfur Dioxide Studies in Shenandoah NP

Shenandoah NP contains at least 189 species of lichens. In 1983, specimens of the rock-inhabiting lichen, Pseudoparmelia baltimorensis, were collected from 64 permanent sampling locations throughout Shenandoah NP and analyzed for sulfur content to reveal potential patterns of accumulation (Lawrey, 1984). Results of this preliminary baseline study led to the following conclusions:

(1)Concentrations of sulfur varied from 0.10% (1000 ppm) dry weight to 0.26% (2600 ppm). Levels above 0.20% (2000 ppm) are considered to be indicative of elevated atmospheric sulfur burdens in the park.

(2)Sites with lichens containing high (greater than 0.20%) sulfur concentrations were found most frequently near Front Royal in the Northern District and in the Sawmill Ridge region in the Southern District.

A second series of investigations was initiated in August of 1984 (Lawrey, 1985). One objective of the 1984 study was to collect a bark-inhabiting lichen species, Pseudoparmelia caperata, from each of the 1983 permanent sampling locations and compare the sulfur values with the P. baltimorensis samples collected in 1983. Another objective was to obtain voucher (U.S. National Herbarium) lichen specimens collected in the past (up to 50 years ago) at various locations throughout the park, collect present-day samples of the same species at each location, and then analyze both historical and present-day samples for total sulfur content to determine if long-term trends in background pollutant levels are apparent. The results of the 1984 study showed the following:

(1)Lichens can be used as indicators of ambient concentrations of sulfur in Shenandoah NP.

(2)Elevated concentrations of sulfur were observed in certain park locations (especially in the Northern District) regardless of the lichen species used in the analysis.

(3)Retrospective analysis of lichen specimens collected in Shenandoah NP in the 1940's and 1950's demonstrated that regional levels of sulfur were increasing throughout the park while levels of lead were shown to be decreasing (Lawrey, 1985, Lawrey and Hale, 1988).

In the Fall of 1985, investigations were initiated to determine more precisely the patterns of sulfur accumulations by lichens in the Northern District of Shenandoah NP, and to relate this information to the presence/absence of certain lichen species thought to be particularly sensitive to atmospheric pollution. Results indicate that the highest sulfur concentrations were in lichens collected in high-elevation sections nearest Skyline Drive. A significant association was observed between site elevation and lichen sulfur content. However, no correlation was observed between lichen sulfur content and presence/absence of the three indicator species in each section. Nevertheless, sections containing no indicator species were clustered near the northern (near the Front Royal entrance) sections of the study area, while the Usnea spp., thought to be most sensitive to SO_2 pollution, were found most frequently in the southern sections (Lawrey, 1987).

5.6 Related Sulfur Dioxide Studies

The SO_2 sensitivities of 35 of the 189 species of lichens known to exist in Shenandoah NP have been studied, nine of which were found to be highly sensitive. According to Wetmore (1983), one species, Ramalina americana, is known to be present when SO_2 levels are below 13 ug/m^3, but absent at levels between 13 and 26 ug/m^3 (annual average).

LeBlanc (1972) conducted a twelve year (1953-1965) study at Sudbury, Ontario, to determine the potential effects of approximately two million tons of SO_2 per year on vegetative resources. LeBlanc found that Ramalina fastigiata (later renamed R. americana by Hale in 1978) was only present where SO_2 concentrations were below 13 ug/m^3, and was always absent where SO_2 concentration values were in the 13-26 ug/m^3 range (annual average).

The annual average SO_2 values of Dickey Ridge from 1983 to 1989, 13.1 to 21.4 ug/m^3 (Table 5-5), are well within the range known to contribute to the absence of R. americana in Canada. Studies should be conducted within Shenandoah NP to determine the presence/absence of R. americana and the total sulfur content when and if the species is found.

5.7 Ambient Ozone Levels in Shenandoah NP

Since 1983 ambient O_3 levels have been monitored by the National Park Service (NPS) at three different locations in Shenandoah NP (Big Meadows, Dickey Ridge, and Sawmill Run). Figures 5-1 through 5-3 and Tables 5-2 through 5-4 show the monthly average ozone concentrations recorded at these three locations from May, 1983 through July, 1990 (data are not available for some time periods). The four highest annual values for each location during 1987, 1988, and 1989 are summarized in Table 5-5 below.

Table 5-2: HIGH OZONE CONCENTRATIONS SUMMARY
SHENANDOAH NATIONAL PARK (BIG MEADOWS)

Year	Month	High Conc. (ppm)	Day of Month	Hour of Day	2nd Hi Conc. (ppm)	Day of Month	Hour of Day	Total # of Days With a Conc. > 0.12 ppm	Raw(R)? Prelim(P)? Final(F)? Data
1983	MAY	0.075	7	1200	0.065	6	1700	0	F
1983	JUN	0.105	15	100	0.100	9	1900	0	F
1983	JUL	0.095	4	100	0.090	28	300	0	F
1983	AUG	0.100	4	1100	0.095	11	1200	0	F
1983	SEP	0.110	9	1700	0.100	10	400	0	F
1983	OCT	0.090	3	1000	0.080	9	1900	0	F
1983	NOV	0.060	9	1500	0.055	2	800	0	F
1983	DEC	0.045	10	1300	0.045	12	1300	0	F
1984	JAN	0.050	10	800	0.050	27	1400	0	F
1984	FEB	0.075	19	1600	0.070	9	1200	0	F
1984	MAR	0.100	20	1600	0.090	16	300	0	F
1984	APR	0.115	12	1700	0.110	13	100	0	F
1984	MAY	0.085	19	1000	0.085	20	200	0	F
1984	JUN	0.100	22	2100	0.090	3	200	0	F
1984	AUG	0.105	15	2000	0.090	16	1100	0	F
1984	SEP	0.080	1	1600	0.075	4	0	0	F
1984	OCT	0.080	5	0	0.075	4	0	0	F
1984	NOV	0.065	15	1600	0.055	26	2000	0	F
1984	DEC	0.035	1	0	0.000	0	0	0	F
1985	JUN	0.075	5	2200	0.070	22	1800	0	F
1985	JUL	0.085	20	900	0.080	19	100	0	F
1985	AUG	0.090	10	300	0.080	29	1500	0	F
1985	SEP	0.095	20	1300	0.085	17	2200	0	F
1985	OCT	0.065	1	0	0.065	8	2000	0	F
1985	NOV	0.045	12	1000	0.045	19	1200	0	F
1985	DEC	0.045	11	900	0.040	2	600	0	F
1986	JAN	0.050	17	900	0.050	18	1300	0	F
1986	FEB	0.060	16	1800	0.055	17	0	0	F
1986	MAR	0.080	31	2300	0.075	25	1500	0	F
1986	APR	0.090	1	1300	0.085	4	1300	0	F
1986	JUN	0.085	19	2000	0.085	22	1300	0	F
1986	JUL	0.085	5	100	0.085	14	1500	0	F
1986	AUG	0.100	5	1800	0.085	2	0	0	F
1986	SEP	0.070	6	1500	0.065	14	2200	0	F
1986	OCT	0.060	21	2200	0.060	22	0	0	F
1986	NOV	0.050	2	1300	0.046	25	500	0	F
1986	DEC	0.045	23	300	0.042	6	1000	0	F

Table 5-2: HIGH OZONE CONCENTRATIONS SUMMARY
SHENANDOAH NATIONAL PARK (BIG MEADOWS) (Cont.)

Year	Month	High Conc. (ppm)	Day of Month	Hour of Day	2nd Hi Conc. (ppm)	Day of Month	Hour of Day	Total # of Days With a Conc. > 0.12 ppm	Raw(R)? Prelim(P)? Final(F)? Data
1987	JAN	0.044	10	1400	0.044	30	1300	0	F
1987	FEB	0.053	26	1400	0.051	24	2100	0	F
1987	MAR	0.070	8	1400	0.068	7	1800	0	F
1987	APR	0.073	11	1200	0.072	22	1700	0	F
1987	MAY	0.096	29	1200	0.090	18	1000	0	F
1987	JUN	0.108	18	1800	0.090	30	2100	0	F
1987	JUL	0.113	25	1200	0.097	1	0	0	F
1987	AUG	0.098	11	2100	0.096	21	1900	0	F
1987	SEP	0.085	4	1600	0.080	10	2300	0	F
1987	OCT	0.085	17	1600	0.081	19	1800	0	F
1987	NOV	0.076	1	1200	0.075	2	100	0	F
1987	DEC	0.045	8	600	0.043	24	1800	0	F
1988	JAN	0.057	30	2200	0.050	31	0	0	F
1988	FEB	0.049	19	1100	0.049	29	0	0	F
1988	MAR	0.076	29	1500	0.075	3	200	0	F
1988	APR	0.071	5	1400	0.071	26	1600	0	F
1988	MAY	0.105	31	1600	0.104	30	1000	0	F
1988	JUN	0.106	16	1200	0.103	7	2200	0	F
1988	JUL	0.137	7	2300	0.129	8	100	2	F
1988	AUG	0.107	16	1300	0.095	12	1000	0	F
1988	SEP	0.075	2	400	0.074	3	1700	0	F
1988	OCT	0.071	16	1500	0.066	17	100	0	F
1988	NOV	0.057	4	1500	0.055	16	1400	0	F
1988	DEC	0.047	7	1200	0.045	19	2100	0	F
1989	JAN	0.056	18	1500	0.051	31	1400	0	F
1989	FEB	0.066	14	1400	0.054	28	1500	0	F
1989	MAR	0.071	28	1400	0.068	27	1700	0	F
1989	APR	0.083	13	1500	0.074	27	2100	0	F
1989	MAY	0.084	30	1300	0.074	22	2300	0	F
1989	JUN	0.097	26	1400	0.081	27	1000	0	F
1989	JUL	0.082	26	1100	0.074	7	1900	0	F
1989	AUG	0.078	18	1300	0.075	16	1500	0	F
1989	SEP	0.070	1	900	0.065	8	1300	0	F
1989	OCT	0.081	14	1400	0.077	13	1500	0	F
1989	NOV	0.059	13	2100	0.054	14	200	0	F
1989	DEC	0.050	31	400	0.049	6	1800	0	F
1990	JAN	0.066	5	1000	0.044	28	1400	0	F
1990	FEB	0.050	13	1900	0.050	14	1600	0	F
1990	MAR	0.069	22	1900	0.066	14	1700	0	F

1990	APR	0.126	4	1500	0.116	18	1500	1	F
1990	MAY	0.080	8	2000	0.076	9	300	0	F
1990	JUL	0.091	4	1800	0.089	5	1200	0	P

Table 5-3: HIGH OZONE CONCENTRATIONS SUMMARY
SHENANDOAH NATIONAL PARK (DICKEY RIDGE)

Year	Month	High Conc. (ppm)	Day of Month	Hour of Day	2nd Hi Conc. (ppm)	Day of Month	Hour of Day	Total # of Days With a Conc. > 0.12 ppm	Raw(R)? Prelim(P)? Final(F)? Data
1983	MAY	0.090	13	1900	0.085	7	1600	0	F
1983	JUN	0.100	9	1800	0.100	22	1900	0	F
1983	JUL	0.110	15	2000	0.110	16	1900	0	F
1983	AUG	0.095	4	1200	0.080	8	2000	0	F
1983	SEP	0.065	28	1300	0.045	29	0	0	F
1983	OCT	0.090	3	1200	0.080	9	1400	0	F
1983	NOV	0.065	2	1700	0.065	9	1100	0	F
1983	DEC	0.045	10	1400	0.040	15	1500	0	F
1984	JAN	0.055	23	1500	0.055	27	1600	0	F
1984	FEB	0.070	19	1600	0.066	9	1300	0	F
1984	MAR	0.080	16	500	0.080	20	1600	0	F
1984	APR	0.110	27	1700	0.105	26	1900	0	F
1984	MAY	0.095	19	1000	0.085	20	0	0	F
1984	JUN	0.105	13	1300	0.100	12	1400	0	F
1984	JUL	0.090	13	1800	0.090	14	1100	0	F
1984	AUG	0.085	16	1100	0.085	22	1800	0	F
1984	SEP	0.060	26	0	0.055	25	2200	0	F
1984	OCT	0.075	4	2100	0.075	5	0	0	F
1985	JUN	0.095	30	1400	0.070	25	2000	0	F
1985	JUL	0.105	20	1300	0.095	9	2100	0	F
1985	AUG	0.105	14	1100	0.095	9	1900	0	F
1985	SEP	0.100	19	1300	0.100	20	1600	0	F
1985	OCT	0.070	1	200	0.060	8	1800	0	F
1985	NOV	0.050	10	1400	0.050	12	0	0	F
1985	DEC	0.045	9	1200	0.045	11	500	0	F
1986	JAN	0.045	12	1200	0.045	17	900	0	F
1986	FEB	0.055	16	1800	0.050	17	0	0	F
1986	MAR	0.080	26	1600	0.075	25	1600	0	F
1986	APR	0.080	28	1700	0.075	4	1900	0	F
1986	MAY	0.075	1	1200	0.075	11	2200	0	F
1986	JUN	0.080	21	2300	0.080	22	100	0	F
1986	JUL	0.085	7	2100	0.080	5	200	0	F
1986	AUG	0.100	13	1600	0.090	2	200	0	F
1986	SEP	0.070	14	1300	0.065	1	0	0	F
1986	OCT	0.060	8	1600	0.060	22	1200	0	F
1986	NOV	0.043	2	1300	0.042	7	1300	0	F
1986	DEC	0.040	23	200	0.038	15	1300	0	F

Table 5-3: HIGH OZONE CONCENTRATIONS SUMMARY
SHENANDOAH NATIONAL PARK (DICKEY RIDGE) (Cont.)

Year	Month	High Conc. (ppm)	Day of Month	Hour of Day	2nd Hi Conc. (ppm)	Day of Month	Hour of Day	Total # of Days With a Conc. > 0.12 ppm	Raw(R)? Prelim(P)? Final(F)? Data
1987	JAN	0.040	6	2000	0.039	26	1400	0	F
1987	FEB	0.058	24	1500	0.053	25	1600	0	F
1987	MAR	0.073	8	1500	0.071	7	1500	0	F
1987	APR	0.083	22	1800	0.078	11	1300	0	F
1987	MAY	0.103	18	1200	0.099	30	1000	0	F
1987	JUN	0.102	18	2000	0.093	17	2000	0	F
1987	JUL	0.124	23	2200	0.118	24	1300	0	F
1987	AUG	0.109	4	1300	0.102	12	1600	0	F
1987	SEP	0.087	4	1700	0.084	10	2300	0	F
1987	OCT	0.083	17	1900	0.082	19	1700	0	F
1987	NOV	0.077	3	1600	0.076	4	1600	0	F
1987	DEC	0.044	24	1700	0.041	9	1300	0	F
1988	JAN	0.059	30	2000	0.048	24	1400	0	F
1988	FEB	0.049	15	1100	0.048	18	400	0	F
1988	MAR	0.078	29	1600	0.074	30	1500	0	F
1988	APR	0.078	27	1400	0.077	6	1500	0	F
1988	MAY	0.119	29	2100	0.116	30	1100	0	F
1988	JUN	0.123	8	1000	0.116	16	900	0	F
1988	JUL	0.151	7	2000	0.142	8	400	2	F
1988	AUG	0.099	16	1700	0.099	17	1200	0	F
1988	SEP	0.097	1	1900	0.085	2	400	0	F
1988	OCT	0.063	1	400	0.051	2	0	0	F
1988	NOV	0.051	16	1400	0.039	15	2200	0	F
1988	DEC	0.036	7	1300	0.035	19	1900	0	F
1989	JAN	0.040	28	2200	0.039	29	0	0	F
1989	FEB	0.048	1	1400	0.042	13	2000	0	F
1989	MAR	0.077	26	1700	0.075	27	1700	0	F
1989	APR	0.069	21	1300	0.069	27	2000	0	F
1989	MAY	0.087	22	2300	0.087	23	0	0	F
1989	JUN	0.100	26	1300	0.095	27	1000	0	F
1989	JUL	0.084	11	1400	0.082	15	2000	0	F
1989	AUG	0.080	16	1500	0.080	28	1300	0	F
1989	SEP	0.082	28	1300	0.073	1	1100	0	F
1989	OCT	0.088	13	1800	0.086	14	1700	0	F
1989	NOV	0.062	13	2200	0.059	14	300	0	F
1989	DEC	0.049	6	1700	0.046	10	1700	0	F
1990	JAN	0.048	16	1300	0.045	15	2300	0	F
1990	FEB	0.054	13	1900	0.053	8	1800	0	F
1990	MAR	0.074	22	1900	0.070	14	1500	0	F

1990	APR	0.094	27	1600	0.086	24	1500	0	F
1990	MAY	0.071	31	2000	0.070	8	2000	0	F
1990	JUN	0.088	14	2000	0.085	1	1800	0	F
1990	JUL	0.088	19	1100	0.085	9	1300	0	P

Table 5-4: HIGH OZONE CONCENTRATIONS SUMMARY
SHENANDOAH NATIONAL PARK (SAWMILL RUN)

Year	Month	High Conc. (ppm)	Day of Month	Hour of Day	2nd Hi Conc. (ppm)	Day of Month	Hour of Day	Total # of Days With a Conc. > 0.12 ppm	Raw(R)? Prelim(P)? Final(F)? Data
1983	MAY	0.075	28	1500	0.065	19	200	0	F
1983	JUN	0.090	9	1500	0.080	15	1200	0	F
1983	JUL	0.110	15	1300	0.100	13	1100	0	F
1983	AUG	0.120	5	1100	0.115	8	1300	0	F
1983	SEP	0.110	3	1300	0.110	10	1100	0	F
1983	OCT	0.090	3	1200	0.075	9	1900	0	F
1983	NOV	0.060	2	1800	0.060	9	1200	0	F
1983	DEC	0.045	7	1000	0.045	15	1200	0	F
1984	JAN	0.050	27	1300	0.045	10	700	0	F
1984	FEB	0.070	19	1500	0.065	10	1500	0	F
1984	MAR	0.070	15	1500	0.070	16	900	0	F
1984	APR	0.110	27	1400	0.100	26	1500	0	F
1984	MAY	0.090	11	1800	0.090	19	1200	0	F
1984	JUN	0.095	11	1200	0.090	5	1900	0	F
1984	JUL	0.105	14	1300	0.095	13	1600	0	F
1984	AUG	0.085	8	1300	0.080	15	1500	0	F
1984	SEP	0.080	1	1600	0.080	14	1200	0	F
1984	OCT	0.060	27	1500	0.055	31	1700	0	F
1984	NOV	0.055	26	1700	0.050	10	1200	0	F
1984	DEC	0.040	3	700	0.040	8	1300	0	F
1985	JAN	0.040	14	1300	0.035	1	1300	0	F
1985	JUN	0.080	25	1500	0.075	22	1400	0	F
1985	JUL	0.085	20	1000	0.080	14	1300	0	F
1985	AUG	0.095	11	1400	0.085	9	1300	0	F
1985	SEP	0.110	20	1100	0.090	19	1500	0	F
1985	OCT	0.085	1	1400	0.060	9	1200	0	F
1985	NOV	0.050	9	1400	0.050	10	1200	0	F
1985	DEC	0.050	10	1400	0.045	9	1200	0	F
1986	JAN	0.050	17	1200	0.050	18	1100	0	F
1986	FEB	0.060	16	1600	0.050	15	1400	0	F
1986	MAR	0.075	25	1500	0.075	30	1100	0	F
1986	APR	0.090	1	1400	0.085	26	1300	0	F
1986	MAY	0.090	5	1600	0.085	30	1300	0	F
1986	JUN	0.090	1	1200	0.085	22	1300	0	F
1986	JUL	0.085	7	1500	0.085	21	1200	0	F
1986	AUG	0.085	5	1700	0.085	26	1100	0	F
1986	SEP	0.065	1	900	0.065	6	1200	0	F
1986	OCT	0.060	22	1200	0.060	24	1400	0	F
1986	NOV	0.053	4	1400	0.046	2	1400	0	F
1986	DEC	0.037	8	1500	0.036	15	1500	0	F

Table 5-4: HIGH OZONE CONCENTRATIONS SUMMARY
SHENANDOAH NATIONAL PARK (SAWMILL RUN) (Cont.)

Year	Month	High Conc. (ppm)	Day of Month	Hour of Day	2nd Hi Conc. (ppm)	Day of Month	Hour of Day	Total # of Days a Conc. > 0.12 ppm	Raw(R)? Prelim(P)? Final(F)? With Data
1987	JAN	0.045	27	1500	0.043	30	1400	0	F
1987	FEB	0.064	25	1600	0.061	24	1400	0	F
1987	MAR	0.070	7	1600	0.070	8	1400	0	F
1987	APR	0.075	11	1100	0.072	29	1500	0	F
1987	MAY	0.097	10	1500	0.092	11	1600	0	F
1987	JUN	0.095	18	1000	0.085	30	2000	0	F
1987	JUL	0.124	25	1200	0.099	19	1300	0	F
1987	AUG	0.097	12	1300	0.096	4	1300	0	F
1987	SEP	0.095	3	2000	0.088	4	1500	0	F
1987	OCT	0.086	17	1500	0.085	19	1500	0	F
1987	NOV	0.078	1	1300	0.076	3	1500	0	F
1987	DEC	0.044	24	1300	0.041	20	1400	0	F
1988	JAN	0.049	30	1300	0.044	12	1200	0	F
1988	FEB	0.050	29	1300	0.049	28	1500	0	F
1988	MAR	0.086	24	1100	0.076	29	1500	0	F
1988	APR	0.071	27	1300	0.069	5	1500	0	F
1988	MAY	0.104	31	1400	0.098	29	1600	0	F
1988	JUN	0.114	22	1100	0.109	14	1500	0	F
1988	JUL	0.143	7	2100	0.129	8	1400	2	F
1988	AUG	0.099	17	1100	0.097	12	1200	0	F
1988	SEP	0.077	2	1300	0.076	3	1100	0	F
1988	OCT	0.070	16	1400	0.060	17	1300	0	F
1988	NOV	0.056	16	1300	0.047	26	1400	0	F
1988	DEC	0.050	23	400	0.045	10	700	0	F
1989	JAN	0.046	29	1900	0.043	18	1300	0	F
1989	FEB	0.053	1	1400	0.050	11	1500	0	F
1989	MAR	0.079	26	1700	0.072	27	1700	0	F
1989	APR	0.062	29	0	0.061	30	1500	0	F
1989	MAY	0.076	22	2200	0.075	18	1400	0	F
1989	JUN	0.088	27	1200	0.079	26	1100	0	F
1989	JUL	0.088	26	1400	0.069	8	1200	0	F
1989	AUG	0.077	31	1500	0.075	16	1300	0	F
1989	SEP	0.068	1	1000	0.060	9	1300	0	F
1989	OCT	0.086	14	1300	0.079	13	1500	0	F
1989	NOV	0.056	14	1400	0.054	13	1500	0	F
1989	DEC	0.042	6	1700	0.039	10	1400	0	F
1990	JAN	0.039	16	1300	0.039	27	1600	0	F
1990	FEB	0.051	14	1500	0.049	9	1600	0	F
1990	MAR	0.077	22	1400	0.073	21	1400	0	F
1990	APR	0.086	27	1200	0.082	26	1300	0	F

1990	MAY	0.093	26	800	0.070	8	1700	0	F
1990	JUN	0.080	14	1000	0.080	29	1400	0	F
1990	JUL	0.084	4	1500	0.081	5	1100	0	P

TABLE 5-5: OZONE DATA SUMMARY 1987 - 1989

(4 HIGHEST VALUES RECORDED FOR THE YEAR BY SITE)

BIG MEADOWS

1987	1.	0.113 ppm July 23, 1987 at 1200 Hours
	2.	0.108 ppm June 18, 1987 at 1800 Hours
	3.	0.098 ppm August 11, 1987 at 2100 Hours
	4.	0.097 ppm July 1, 1987 at 0 Hours
1988	1.	0.137 ppm July 7, 1988 at 2300 Hours
	2.	0.129 ppm July 8, 1988 at 0100 Hours
	3.	0.107 ppm August 16, 1988 at 1300 Hours
	4.	0.106 ppm June 16, 1988 at 1200 Hours
1989	1.	0.097 ppm June 26, 1989 at 1400 Hours
	2.	0.084 ppm May 30, 1989 at 1300 Hours
	3.	0.083 ppm April 13, 1989 at 1500 Hours
	4.	0.082 ppm July 26, 1989 at 1100 Hours

DICKEY RIDGE

1987	1.	0.124 ppm July 23, 1987 at 2200 Hours
	2.	0.118 ppm July 24, 1987 at 1300 Hours
	3.	0.112 ppm July 25, 1987 at 1900 Hours
	4.	0.111 ppm July 29, 1987 at 2100 Hours
1988	1.	0.151 ppm July 7, 1988 at 2000 Hours
	2.	0.142 ppm July 8, 1988 at 0400 Hours
	3.	0.123 ppm June 8, 1988 at 1000 Hours
	4.	0.119 ppm May 29, 1988 at 2100 Hours
1989	1.	0.100 ppm June 26, 1989 at 1300 Hours
	2.	0.095 ppm June 27, 1989 at 1000 Hours
	3.	0.088 ppm October 13, 1988 at 1800 Hours
	4.	0.087 ppm May 23, 1989 at 0 Hours

SAWMILL RUN

1987	1.	0.124 ppm July 25, 1987 at 1200 Hours
	2.	0.099 ppm July 19, 1987 at 1300 Hours
	3.	0.098 ppm July 24, 1987 at 1400 Hours
	4.	0.098 ppm July 21, 1987 at 1300 Hours
1988	1.	0.143 ppm July 7, 1988 at 2100 Hours
	2.	0.129 ppm July 8, 1988 at 1400 Hours
	3.	0.114 ppm June 22, 1988 at 1100 Hours
	4.	0.113 ppm July 10, 1988 at 1100 Hours
1989	1.	0.088 ppm July 26, 1989 at 1400 Hours

2. 0.088 ppm June 27, 1989 at 1200 Hours
3. 0.086 ppm October 14, 1989 at 1300 Hours
4. 0.079 ppm October 13, 1989 at 1500 Hours

5.8 Ozone Studies in Shenandoah NP

As shown in Table 5-5, ozone concentration values at Shenandoah NP are well above those known to cause foliar injury and growth reductions to sensitive vegetation species. In particular 1988 was an exceptionally bad year for O_3, with all three stations recording exceedances of the Federal primary standard of 0.12 parts per million (ppm). It has been found that foliar injury and significant growth and yield reductions in sensitive species result from ozone concentrations below the national standards.

In September, 1982 the NPS surveyed six ozone sensitive plant species in Shenandoah NP to evaluate the presence and magnitude of ozone injury. The species surveyed included: eastern white pine (Pinus strobus), tulip poplar (Liriodendron tulipifera), black locust (Robinia pseudoacacia), wild grape (Vitis spp.), virgin's bower (Clematis virginiana), and common milkweed (Asclepias syriaca). The studies were conducted to evaluate overall park injury and to determine if any damage patterns could be ascertained in east-west, north-south, and elevational distribution. In addition, studies were conducted to determine the growth rates of tulip poplar trees with and without ozone foliar injury. Foliar injury was observed on all six species at all locations where each species occurred. Injury on some species appeared to increase from north to south in the park, while on others the injury pattern was reversed (e.g. milkweed). The tulip poplar tree growth rate study was conducted on thirty-two trees near milepost 71 on Skyline Drive. The trees were rated for visible injury and cored to measure growth rates. Two cores per tree were taken and the radial growth from 1970 to 1982 was measured. Injury, defined as percent injury per leaf times percent of leaves injured, ranged from 0 to 78%. There were significant differences between injury ratings and growth averages for the three injury classes of trees (i.e. sensitive, intermediate, tolerant). Trees classified as intermediate and tolerant to ozone showed injury from 0 to 7%, and growth from 2.4 to 6.0 mm/year. Sensitive trees, however, exhibited injury from 11 to 78% and growth increments of 1.3 to 5.2 mm/year. On average, growth in the sensitive trees was 18% less than the intermediate and tolerant trees, while injury was about 1300% greater. The growth decrease from the intermediate to the sensitive trees was statistically significant at the 0.055 probability level. It appeared that the foliar injury and growth reductions were related (Bennett, 1984). In the summer of 1984 a further study was conducted on milkweed and documented the ozone injury over the growing season. Throughout the park, the amount of injury averaged an increase of 11 to 15 times over the course of the summer. As in 1982, the number of injured plants was comparable and increased from south to north.

Additional studies on vegetation were conducted in 1985 and 1986. Studies were conducted in 1985 on yellow poplar (Liriodendron tulipifera), white oak (Quercus alba), and red maple (Acer rubrum). Results showed that 3% of the yellow poplars, 5% of the white oaks, and 9% of the red maples exhibited foliar injury due to O_3 (Sanchini and Stein, 1987). The 1986 (August and September) study evaluated O_3 injury on 326 eastern white pine trees on 22 permanent biomonitoring plots. Chlorotic mottle and tipburn, both symptoms of O_3 injury, affected 1.5% of the needles examined, while 85% of these trees had some O_3 injury. The amount of injury increased with the age of the needle whorls. This high incidence/low severity pattern is similar to that observed in four other eastern national parks in 1985 (Sanchini, 1988). A concurrent study by Sanchini on 743 randomly selected white pine trees throughout the park showed that 79% had low levels of ozone injury (Sanchini, 1989).

A 1985 unpublished Park Service milkweed survey indicated that 97% of the milkweed plants showed some O_3 injury with an average of 69% of the leaves injured, and an average of 8% of the leaf area injured. Hughes et al., (1989) studied the feeding preference of monarch butterflies (Danaus plexippus) on fumigated bloodflower (Asclepias curassavica) and common milkweed (Asclepias syriaca) versus controls. They found that the larvae developed faster on fumigated plants. The cardenolides, toxins in the plants that make monarch butterflies unpalatable to insectivorous birds, showed variable responses to O_3 fumigation. The long-term effects of feeding on ozone-injured plants on the growth, reproduction, and population dynamics of monarch butterflies are unknown.

In a fumigation study in which tree samples were collected and clonally propagated from nine eastern national parks, Karnosky et al., (1986) reported that clones of red maple from three parks, including Shenandoah, with historically high ozone levels showed smaller amounts of ozone injury. The authors suggested that sensitive genotypes were being eliminated from the park. Woodman (1987) reported on published studies by Skelly et al., and Duchelle et al., in which seedlings of white pine and other tree species in Shenandoah were raised in fumigation chambers. Height growth of seedlings was greater in chambers in which ozone and other gaseous pollutants were excluded than was height growth of seedlings grown in ambient air.
These studies demonstrate that ozone concentrations high enough to cause foliar injury and growth effects to sensitive species have occurred in Shenandoah NP in recent years. Also, as mentioned above, ambient monitoring data indicate that ozone concentrations at the park continue to remain high. Although studies in other areas have shown that the observed effects (e.g., visible injury, growth reductions) could lead to widespread ecological change, at present, there are no predictive models available to allow an accurate estimation of when ecological effects might occur given a particular pollution scenario. The Federal Land Manager reasonably believes that change in the structure and functioning of any component of an ecosystem affects the ecosystem in some way, however subtle. Because ozone related injury already exists in the park, the Federal Land Manager reasonably believes that any increase in VOC or NO_x emissions will exacerbate current conditions.

5.9 Potential Impact of Increased Emissions

Studies conducted from 1982-1986 have demonstrated that ozone concentrations (see Table 5-5) high enough to cause foliar injury and growth effects in sensitive vegetation species have occurred in Shenandoah NP, especially in the northern district. Visible leaf foliar injury (discoloration) indicates cells have been killed by ozone and are no longer able to continue photosynthesis and other metabolic activities. In general, this injury lowers the physiological vigor and changes the foliar metabolites of the individual plant. The ramifications of this injury for the plant and animal ecosystem of Shenandoah NP are not known at this time. Sulfur loadings currently occurring (2600 ppm) at Shenandoah are well above background levels (1000 ppm) and in a range known to cause morphological changes in some species of lichens. Ambient SO_2 levels being recorded (1983-1989) at the Dickey Ridge monitoring station (13-21 ug/m^3 annual average) are within the range known to have contributed to the absence of the lichen species Ramalina americana in Canada. A literature search conducted by NPS biologists recently found that of the 1136 vascular plants species known to exist in Shenandoah NP, ozone sensitivity studies had been reported for 79 species and sulfur dioxide sensitivity studies had been reported for 96 species. Twenty-three vascular plant species were shown to be ozone sensitive, and 21 were shown to be sulfur dioxide sensitive. Therefore, we are concerned that ecological impacts due to ozone and/or sulfur loadings may already be occurring and that additional NO_x and VOC (ozone precursors) and/or SO_2 emissions in the area may exacerbate the existing conditions.

Based on the above findings and discussion, as with visibility and aquatic effects, the Federal Land Manager concludes that the present terrestrial effects at Shenandoah NP meet the adverse impact criteria discussed above, and therefore are adverse. Again, the Federal Land Manager also reasonably believes that the effects of the additional SO_2, NO_x, and VOC emissions associated with the electric generating stations proposed for the area would contribute to the existing adverse terrestrial effects and are unacceptable.

6.0 OVERALL CONCLUSIONS

Based on the above information, the Federal Land Manager has preliminarily determined that visibility, aquatic, and terrestrial resources at Shenandoah NP are currently being severely affected by air pollution. These air pollution effects are a chronic problem, which interfere with the management, protection, and preservation of park resources and values, and diminish visitor enjoyment. Therefore, consistent with his legal responsibilities and management objectives for Shenandoah NP, the Federal Land Manager concludes that the current air pollution effects at Shenandoah NP are adversely affecting the air quality related values at the park.

One possible approach to mitigating these adverse conditions at the park is that the Virginia Department of Air Pollution Control not permit additional major air pollution sources with the potential to affect Shenandoah NP's resources unless it can be assured that such sources would not contribute to the adverse impacts. Another possible remedy is for the State to develop and implement a Statewide emissions control strategy to protect the air quality related values of Shenandoah NP. Such a strategy could include (1) an offset program requiring a greater than one-for-one emission reduction elsewhere in the State to offset proposed emission increases associated with major new or modified sources; and (2) a provision setting a timeframe for determining maximum allowable levels of air pollutants in the State, which would involve Statewide emission caps as a primary method for achieving these maximum allowable levels. This emissions cap could reflect a level of allowable pollution that will provide long term protection for critical natural resources throughout the Commonwealth of Virginia.

The Federal Land Manager will consider the above possible approaches, as well as any additional alternatives received through the public comment process, in making final recommendations to the Virginia Department of Air Pollution Control.

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